# 13.—THE GEOLOGY AND PHYSIOGRAPHY OF THE MALKUP AREA,

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Read 11th June, 1940; Published 8th November, 1940.

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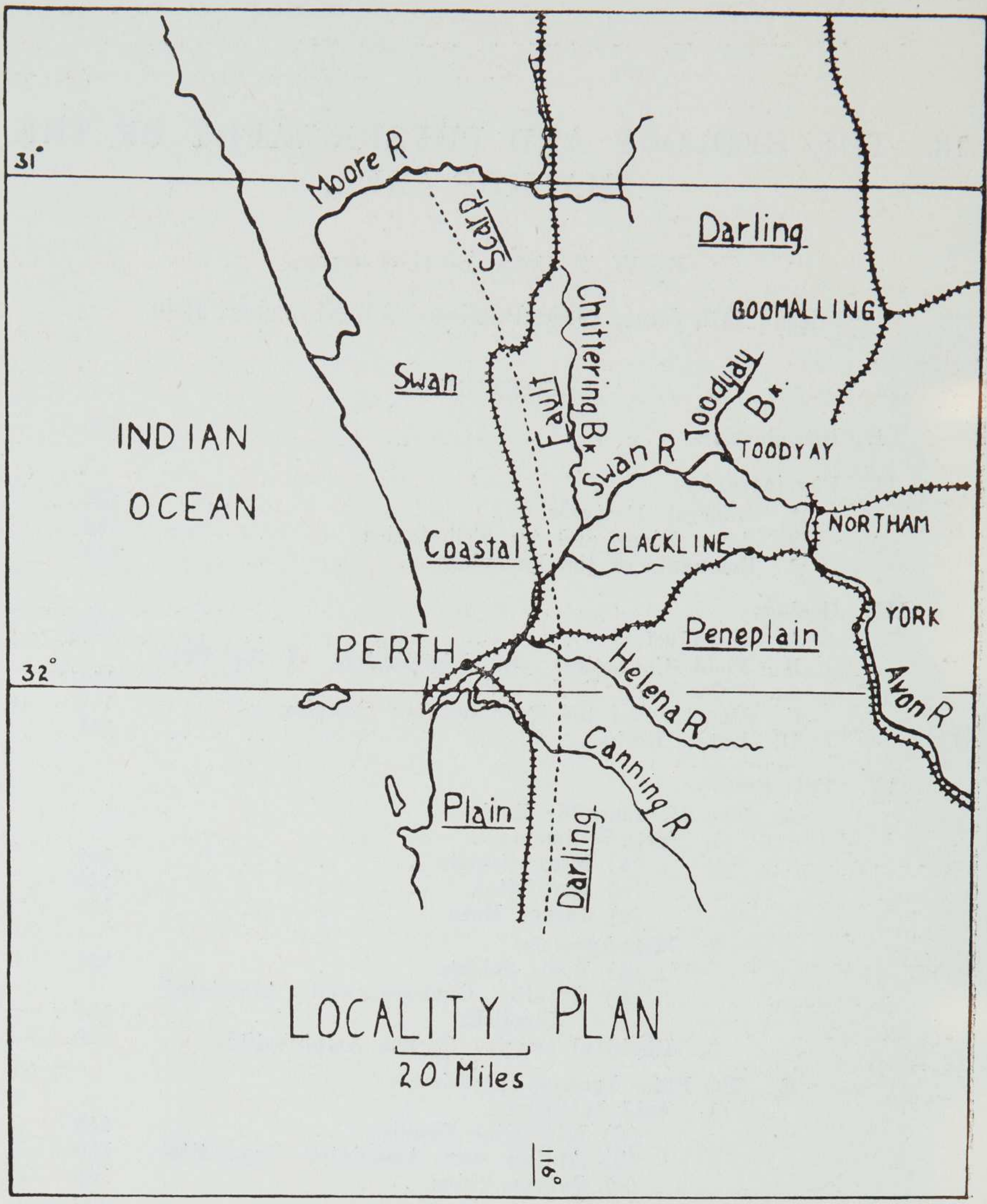


Fig. 1.—Locality Plan on which is shown the relative positions of the Swan Coastal Plain, Darling Peneplain, and Darling Fault Scarp (after Jutson).

## I.—INTRODUCTION.

The Malkup Area is situated about 55 miles by road in a north-easterly direction from Perth and about 12 miles west of Toodyay (Fig. 1), and comprises part of the Pre-Cambrian complex. The southern portion of the area is joined on the east by the Jimperding Area, mapped by R. T. Prider (1934).

The area, which covers about ten square miles, lies in the South-West Land Division of Western Australia which may be divided physiographically into (Jutson, 1934, p. 84)—

1. The Swan Coastal Plain.
2. The Darling Peneplain and Darling Fault Scarp.

The Darling Fault Scarp which has been traced in a north-south direction for over 200 miles, rises sharply from the Swan Coastal Plain to an elevation of about 800-1,000 feet above sea level and forms the western edge of the Darling Peneplain. The Peneplain was once entirely covered by a laterite capping a few feet thick (Woolnough, 1918) but is now well dissected by rivers in various stages of maturity.

Erosion has disclosed two main groups of Pre-Cambrian rocks.

1. Metamorphosed sedimentary and igneous rocks of the Jimperding and Chittering series (R. T. Prider, 1934; K. R. Miles, 1938).

2. Igneous rocks of the Swan-Helena Type which consist of various granites (gneissic in places) with later doleritic intrusions (Clarke and Williams, 1926; Fletcher and Hobson, 1931).

Although the country around Toodyay was one of the first inland regions of Western Australia to be settled, the Malkup portion of the district has not progressed to any extent, owing to the poor soil, the rugged topography, and the discovery of more accessible and richer land to the east. The few inhabitants of the area derive their living from sheep farming.

Owing to the excellent gradient offered by the Avon River, from Northam to Perth, the Avon valley has been selected for a proposed Transcontinental Railway. When a preliminary survey was made in 1931 heights were determined at intervals of 1 chain along the proposed route and pegs inserted at every five chains. These pegs (the heights of which were obtained from the W.A. Government Railways) proved invaluable reference points for contouring.

As the area has been subdivided by the Lands and Survey Department, a detailed preliminary survey was not necessary. Most of the geological and topographical features were mapped by chain and compass traverses. The form lines were drawn from aneroid barometer readings working from the railway heights as data.

The greater part of the southern half of the area was mapped by the authors alone, but the northern half was mapped and contoured during the first term vacation of 1938 by the authors with parties of senior University students, under the leadership of Professor E. de C. Clarke.

## II.—PHYSIOGRAPHY.

### A. *General Features.*

The Malkup Area is a part of the drainage basin of the Swan-Avon River in which the river has cut deeply into the Darling Peneplain. The average height above sea level of the Avon Valley is about 350 feet, while the residuals of the peneplain (which cover about one-tenth of the surface area) are generally over 850 feet rising to a maximum of about 1,000 feet. On many maps this part of the Swan-Avon River is shown as the Swan River, but, in accordance with local usage, it will be referred to as the Avon in this paper.

According to Jutson (1934, p. 169) the Darling Peneplain was developed in Pre-Pleistocene times, and, later, rose to its present elevation, with the formation of the Darling Fault Scarp on its western edge. The effect of uplift was to produce a general tilt towards the south-east, initiating a new cycle of erosion in the form of consequent south-easterly flowing streams.

At the same time other more vigorous consequent streams were working back from the western coast. The west flowing streams ultimately, by headward erosion, captured parts of the south-easterly flowing streams.

The Avon River in the Malkup Area is part of the consequent western coast stream system which has captured, farther west, the waters of Chittering Brook and, just east of the Area, the waters of Toodyay Brook.

### B. *The Avon River and its Tributaries.*

Within the Malkup Area the Avon River and its three main tributaries, Malkup, Mortigup and Munnapin Brooks, are all intermittent and in summer only the deeper pools of the Avon River contain water.

1. *The Avon River.*—The Avon River enters the Malkup Area near the south-east corner, flows slightly north of west for about two miles, then swings to the north in a broad arc which flattens out and turns south-west as the river leaves the Area. In this short distance there is thus little manifestation of the general south-west trend of the river.

On the whole the Avon Valley in the Malkup Area is intermediate in character between the broad mature valley at Northam and the gorge at Upper Swan (Fletcher and Hobson, 1931) where the river breaks through the Darling Fault Scarp. Indeed in the Area itself there is a gradual change from early mature in the eastern part of the valley to the more youthful cross-profile of the western.

The Avon Valley is asymmetrical in cross-profile throughout the Malkup Area. This asymmetry suggests a northerly migration of the river—a suggestion which is supported by the occurrence on the south side of the river of several "flights" of river terraces from 3 feet to 5 feet high and about one chain apart.

A flattened area, about ¾ mile south of the point where the Avon changes the direction of its course from north-west to south-west and about 500 feet above sea level, may possibly be correlated with Woolnough's high level river terraces which he terms the "Meckering Level." Such a level surface could be due (Woolnough, 1919, p. 390) to a small elevation subsequent to the formation of the Darling Peneplain and before its elevation to its present altitude.

A glance at the distribution of rock types in the Malkup Area, as shown on the geological map (Plate 1), does not reveal any explanation for the present course of the Avon River. As will be explained in a later section of this paper the structure of the Area is that of an anticline, the core of which is occupied by an intrusive granite gneiss. This weak structural unit offered to the Avon River, after its initiation by uplift of the peneplain in Pleistocene times, an easy path to base level. Since these times the metasedimentary series forming the upper part of the anticline has been removed and the intrusive granite gneiss of the core has been exposed. Time did not permit of an investigation into the structures developed in this gneissic core but later detailed surveys of this gneiss may indicate the existence of certain structures which may be correlated with the suggested anticlinal structure of the metasedimentary series and also with the present course of the Avon River. At present it is suggested that the Avon Valley in the greater part of the Malkup Area is an example of a superposed stream, i.e., its course has been determined by the trend of a structural unit which has now been almost completely removed. The course of the Avon in the massive granite has been determined by the presence of main joint systems.

Pools on the upstream side of the mouths of the main tributaries except Mortigup Brook are characteristic of this part of the Avon. The average length of these pools is a quarter of a mile and their depth varies, but probably does not exceed 15 feet-20 feet. They appear to originate as a result of the damming back of the waters of the Avon River by the formation of a bar, at the tributary mouths, from sediment brought down by the flood waters of the tributaries.

2. *The Tributaries of the Avon.*—There is some evidence to suggest that the three main tributaries of the Avon River (Malkup, Mortigup and Munnapin Books) once formed part of a south-east drainage system which was later captured by headward erosion of the Avon. Malkup Brook may have once been continuous with the upper reaches of Mortigup Brook, and Munnapin Brook may have once represented another distinct system.

*Malkup Brook.*—According to the maps of the Lands Department on which its course is sketched, Malkup Brook flows south from its source for about 20 miles and enters the Avon River at about the centre of the Malkup Area. Except for the last mile, where, after being joined by a fairly large eastern branch, it flows due west, its course is most irregular. The few other tributaries are merely small subsequent streams whose profiles flatten out as they approach Malkup Brook. Although waterfalls are common in Malkup Brook the valley as a whole may be described as early mature because the cross-profile both above and below the falls is in keeping with this generalisation. In several places the stream has deposited considerable amounts of alluvium.

*Munnapin Brook.*—This stream lies in the north-west of the Area, and shows the dependence of the cross-profile on the type of underlying rock. Where the brook flows through granite it possesses a steep gradient accentuated by many small waterfalls but its valley becomes more mature where its course coincides with the contact of the granite and metamorphic series. Here, meandering across an alluvium covered flood plain, it has altered its course several times, as shown by the presence of "deserted bends." The eastern tributaries are rapidly dissecting the metasedimentary series but the western tributaries have as yet made little impression on the harder more resistant granite.

*Mortigup Brook.*—Mortigup Brook forms the main drainage system of the south-western portion of the area. The presence of a mature valley in its upper reaches suggests the possibility that Mortigup Brook was originally a south flowing stream, perhaps a continuation of Malkup Brook which has been captured and reversed by the Avon River. In its middle course Mortigup Brook is characterised by two sharp right angled bends which are due in both cases to well developed jointing in the granite. From here to its junction with the Avon River, the stream flows through an early mature valley with tributaries from the west actively dissecting the laterite capped plateau.

3. *Minor Features.*—Waterfalls occur only in the tributaries of the Avon River and are due either to vertical or horizontal joints or to very resistant basic dyke bars.

Springs are fairly numerous in the Area and are the only source of water during summer. They do not occur at any particular level, nor does any particular geological factor determine their origin. Many are at the contact of greenstone dykes and granite, but others occur scattered through the granite and gneiss.

Pot holes are common in the Avon River and its tributaries where they flow over granite. The largest noticed was five feet in diameter and five feet deep. They are usually quite symmetrical but unsymmetrical types occur.

### *C. Remnants of the Peneplain.*

The remnants of the peneplain are the high laterite capped hills which are now being actively dissected by the headward erosion of the tributaries of the Avon River. The laterite capping is up to ten feet thick and occurs over all rock types in the area.

## III. GEOLOGY.

### *A. Introductory.*

The Area is essentially composed of metamorphic and igneous rocks, similar to those in the adjoining Jimperding Area, which are believed to be Pre-Cambrian in age (Prider, 1934). They are, in places, masked by the thin deposits of very recent age to which some reference has been made in the preceding section, where a general idea of their distribution is given.

This same belt of metamorphic and igneous rocks extends south-east from Jimperding to Clackline and thence to York (see Fig. 1 for localities). Another occurrence has been noted between Northam and Goomalling (Maitland, 1899, p. 28). The belt probably extends westwards from the Malkup Area to the Chittering Area (Miles, 1938), where it is represented by a series of very high-grade metamorphic rocks, which include kyanite, sillimanite and staurolite schists.

A glance at the geological map (Plate 1) shows that the Pre-Cambrian rocks fall into three groups—metamorphic rocks, granite and basic intrusives. The metamorphic rocks include metasediments which are exposed in the south-east and north-west, and gneisses, which are developed in the south-east, centre and east; the granite occupies the west side of the Area and sends out a wedge in a north-easterly direction; the basic intrusives form dyke-like bodies invading both the metamorphic rocks and the granite.

The prevailing trend of the metamorphic rocks in the south-eastern part of the Area is northerly, whereas in the north-western part it is easterly.

### *B. Field Characters and Distribution of the Pre-Cambrian Rocks.*

#### 1.—Metamorphic Rocks.

##### (a) *Metasedimentary Series.*

*Mica-schist and Quartzite.*—The main metasedimentary series in the south-east and north-west parts of the Area is made up of alternating beds of quartzite and mica schist. These rock types are also developed as small isolated patches in the granite of the west and in the gneiss of the north and north-eastern parts of the Area. Whereas in the south-east the beds strike north-west and dip at an average angle of 35° to the south-west, in the north-west the strike is to the west and the beds dip at an average angle of 35° to the south. In the extreme north-west and north-east dips of 20°-45° to the north have been noted.

The quartzites are well bedded and weather into a flaggy rubble, which frequently obscures the softer schist formation. In many places they grade into mica schists. Lenses of quartzite in the schists are common.

*Jasper Bars.*—These rocks occur in the south-west corner as a narrow band overlying mica schist. Their occurrence is of particular interest because similar rocks have been described from the Bolgart Area north of Toodyay, where they occur as bands in the greenstones (Feldtmann, 1919, p. 27). Prider (1938, p. 62) has noted the occurrence of similar rocks in small xenoliths in granite gneisses in the Toodyay Area east of Malkup. The occurrence of similar rocks in the Goldfields Areas, where they are represented by banded quartz haematite rocks or "jasper bars," has been repeatedly noticed. The Malkup rocks show affinities to the rather rare eulysites.

(b) *Meta-Igneous.*

*Basic Schists.*—The basic schists are usually found inter-bedded with the mica schist and quartzite in the south-east, north-west and western parts of the Area. With one exception they occur as long thin bands difficult to trace in the field. They also occur as xenolithic patches in the granite and gneissic granite. Although all original textures and structures have been completely obliterated the basic schists appear to be original basaltic sills or flows which have been folded along with the meta-sedimentary series.

*Granite Gneisses.*—The granite gneisses may be subdivided into two groups according to the character of the felspar.

(1) *Biotite-microcline-granite gneiss.*—The authors have included under this division the broad band of augen gneiss on the south side of the river and the banded and slightly gneissic outcrops of the opposite side. The augen gneiss which directly underlies the quartzites of the south-east part of the Area, forms a prominent hill, the slopes of which are frequently broken by vertical cliffs (from 10-20 feet high). These cliffs are a result of the predominance of vertical joints in the gneiss. Towards its base the augen gneiss passes into a finely banded gneiss, the exposures of which continue on the north side of the river. This finely banded gneiss has, it is believed, resulted from a complete crushing of the augen in the augen gneiss. A gneissic granite or fluxion gneiss replaces the finely banded gneiss in the north and north-eastern parts of the Area. The fluxion gneiss is usually a rock possessing a faint linear parallelism of biotite flakes which passes into a granite showing crushing and cataclastic effects but no linear stretching.

(ii) *Biotite-oligoclase-granite gneiss.*—This rock type occurs as:—

(a) irregular patches in the fluxion gneiss of the north-eastern part of the area;

(b) an extensive development north of and along the middle and upper reaches of Malkup Brook. Here it is intruded by the microcline granite. The authors have not been able to find the field connection between (a) and (b), but because of their similar mineralogical composition they are conveniently treated together.

*Xenoliths and Hybrid Rock Types.*—In the biotite-microcline-granite gneiss there are xenoliths and irregular patches of more basic well banded gneisses, but no attempt has been made to map all the individual occurrences. In the north-east and eastern sections of the Area a more definite and extensive basification of the fluxion gneiss has taken place. Assimilation of basic igneous material comparable in composition with the basic schists, has produced a hybrid rock which, in mineralogical and textural features, is closely allied to the intermediate quartz-bearing plutonic igneous rock types.

In the biotite-oligoclase granite gneiss finer grained patches, more basic than the surrounding rocks frequently occur. Their general form is that of elongated spindles oriented parallel to the foliation of the surrounding gneiss. Sharp and regular contacts show that there has been little interaction between the two.

### (c) *Doubtful Origin.*

*Garnet Amphibolite.*—This rock type occurs, just south of the mouth of Munnapin Brook, as a small band between beds of mica schist and quartzite. The rock is particularly interesting because of its occurrence in such an environment.

### *Comparison of the Metamorphic Rocks of Malkup Area with Jimperding Area.*

The upper beds of the Jimperding Series continue into the south-eastern part of the Malkup Area. At Jimperding, Prider (1934, p. 6) noted the order given in Table I in the upper part of the conformable metamorphic series.

Table I.

*Comparison of the Metamorphic Rocks of Malkup Area with Jimperding Area.*

| Jimperding Area. | Malkup Area. South-east. | Malkup Area. North-west. |
|---|---|---|
| Micaceous schist (upper most)—250′ | Alternating series of mica schist and quartzite. One band of basic schist 30′ thick—2,000′-700′ | Alternating series of mica schist and quartzite. No definite basic schist bands—2,600′ |
| Basic schist and gneiss —300-350′ | | |
| No. 5 Quartzite—500′ | | |
| Upper Gneiss — 1,800′-1,900′ | Augen gneiss—1,400′-0′ | Not present |

It is to be noted that, whereas the thicknesses of the different horizons are said to be fairly uniform throughout the Jimperding Area and the strike to be westerly with a southerly dip seldom exceeding 20°, as the beds are traced into the Malkup Area the thickness of the formations varies, the strike swings to the north-west, and the dip steepens to an average of 35° to the south-west. The augen gneiss (equivalent to Prider's Upper Gneiss) thins out towards the north-west and also in this direction the quartzites (equivalent to Prider's number 5 quartzite) overlying the augen gneiss are interbedded with a number of bands of mica schist on an average 100 feet thick. The basic schist and gneiss group is represented by a thin band of schist which follows the general strike of the metamorphic series. The metamorphic series of the south-east part of the Malkup Area are continued in the north-west where as has been previously noted the strike changes from north-west to west. Unfortunately the two parts of the Area are separated by a wedge of granite across which it is impossible to correlate the series. The general character and thickness of the series in the north-west part of the Malkup Area are indicated in Table I.

### 2.—Acid Intrusives.

The acid intrusives are represented by a microcline granite and its associated aplites, pegmatites, quartz veins and felspar porphyries.

Grey granite similar to that of Jimperding and of the Darlington Area (see locality map Plate I.) occurs in the west and extends across the Avon in the form of a wedge to separate the north-west from the south-east. The actual intrusive contact of the granite and metamorphic series has not been observed but the frequent occurrence of the metamorphics as xenoliths in the rock, which has been identified microscopically as a granite, leaves no doubt as to its intrusive character. In the south-east part of the Area the boundary between the metamorphic series and the granite follows the strike of the metamorphics, but this is not the case for the remainder of Malkup Area. The granite outcrops form characteristic tors, sloping rock floors, cliffs and waterfalls. The last named are due, as mentioned above, to strong vertical joints.

Aplites, pegmatites, quartz veins and felspar porphyries are all intrusive into the granite and metamorphic series. The precise relationships between these last phase products of the granite magma have not been determined.

### 3.—Basic Intrusives.

The basic intrusives which are younger than the granitic rocks, are represented by dolerite, quartz dolerite and epidiorite.

As at Jimperding the basic intrusives have a predominant regional northerly trend. This is particularly noticeable in the western part of the Area where the dykes scarcely deviate from a north-south line. As no examples were found of dykes cutting through each other it has been assumed that they all belong to the same period of intrusion.

*Xenoliths in the Quartz Dolerite.*—The occurrence of xenolithic bodies in the quartz dolerite was noticed in two places. Firstly in a basic dyke cutting through granite west of the shear zone on the northern side of the Avon River and secondly in a basic dyke about a quarter of a mile north of the mouth of Malkup Brook. These xenoliths are of particular interest because they give some indication of the position of the original basic magma reservoir. This matter receives further attention in the petrographic section.

*Associated Granophyres.*—In the north of the south-east part of the Area a fairly large basic dyke cuts through both the granite-meta-sediment contact and, near that contact, has assimilated the country rocks, in particular, the granite. The result has been the production of a thin band of granophyre around the dyke. A similar rock type is also found where quartzite xenoliths occur in the above dyke. This occurrence of a granophyric margin on quartzite xenoliths would appear to resemble the micropegmatitic margins on quartzite xenoliths at Colonsay, where an ultra basic magma, now represented by hornblendite has engulfed xenoliths of quartzite (Reynolds, 1936). Two further occurrences of granophyre noted, were rather small local features, both due to a dyke marginally modifying the granite.

## *C. Structure of the Pre-Cambrian Complex.*

### 1.—Structures Peculiar to the Metamorphic Rocks.

The general swing of the strike of the metamorphic rocks from west to north-west and back to west, passing from Jimperding through the south-east to the north-west part of the Malkup Area has already been noted.

The east-west strike of the patches of metamorphic rocks in the north-west and north-east parts of the Area, with dips to the north, suggests a possible anticlinal structure for the Area. Unfortunately outcrops of meta-sediments in the north part of the Area are scarce and not much reliance can be placed on dips and strikes of isolated patches. If the suggested structure is correct then the meta-sediments occurring along the arch of the anticline have been removed and a core of intrusive granite gneiss has been exposed. More work farther north of Malkup Area will have to be carried out before the structure will be made clear.

Minor folding in the meta-sediments, particularly the quartzites, is frequently noticeable and occasionally good drag folding occurs. Several readings of drag folding in quartzites above the augen gneiss were made and it was found possible to determine the position of these parts relative to a major structure. Readings indicate the western limb of an anticline overturned to the north-east. This is in keeping with the suggested major structure.

### 2.—Later Fault Zone.

A remarkable brecciated zone occurs about half a mile from the western edge of the Area. Although it has been mapped for a distance of 3 miles in a gently sinuous north-south line a true idea of its width is only obtained where it is cut through by the Avon River and Mortigup Brook, because elsewhere it is obscured by steep talus slopes. To the north it dies out and to the south it disappears beneath laterite. Although the zone forks where it crosses the Avon River only one branch is found on the north side of the river.

The zone appears to be later than the basic dykes of the Area because a rather characteristic platy dyke is found on the east side of it in the south and on the west side of it in the north. Furthermore no dykes are seen to traverse it.

It consists essentially of brecciated granite which has been extensively injected by quartz veins (up to 2 inches wide). Although no actual displacement can be proved (as the zone is confined to granite) the authors consider it to be a shear or fault zone. Prider (1934, p. 5) has recorded a similar fault breccia from the Jimperding Area.

### *D. Later Rocks.*

The later rocks consist of:—

(a) a superficial capping of laterite;

(b) deposits of alluvium on the flood plains of the Avon and its major tributaries.

(c) talus slopes of quartzite, dolerite and laterite on the steeper hill slopes.

It will be noted from the geological map (Plate I.) that except for the occurrence of a number of small plateau residuals on either side of the Avon River in the central part of the Area, the superficial capping of laterite is limited to the extreme edges of the Area.

Reference to the later rocks has already been made in the section on Physiography.

## IV.—PETROGRAPHY.

### A. *The Metamorphic Rocks.*

The metamorphic rocks of Malkup Area have been classified as follows:

1. Meta-Sediments.
2. Meta-Igneous.

#### 1. Meta-Sediments.

These have been subdivided into:—

(a) Mica Schists.
(b) Quartzites.
(c) Jasper Bars.

(a) *Mica Schists.*—The following types are found, indicating that many different grades of metamorphism are present in the mica schists:—

Chlorite-sericite schists.
Biotite and muscovite schists.
Andalusite-mica schists.
Garnet-andalusite-mica schists.
Staurolite-mica schists.
Sillimanite-mica schists.

*Chlorite-sericite schist* marks the lowest grade of metamorphism. The rock type consists of bands of chlorite and sericite, alternating with quartz-felspar bands. The small pale green, pleochroic, chlorite laths show a stellate arrangement, whereas sericite forms small colourless scales disseminated throughout both chlorite and quartz felspar bands.

*Biotite-muscovite schists* are dark brown iron stained rocks. They possess a marked fissile structure, due to the parallel alignment of mica flakes.

In thin section the texture is granoblastic, gneissic, seriate. Muscovite is dominant over biotite and differs from it as regards degree of crystallinity. The deep reddish brown biotite crystals are usually more irregular in form and frequently show sagenite webbing (due to minute acicular crystals of rutile) as well as pleochroic haloes around zircon inclusions. Both micas are set in a quartz-felspar mosaic.

Specimen (17534, section 40579),* a highly contorted and dragfolded schist carries patches of epidote with much haematite. The epidote is slightly pleochroic from colourless to yellow green and has characteristic flecked interference colours. These patches may represent limy intercalations in the sandy argillaceous sediment or some original detrital pebbles.

*Andalusite-mica schists* represent that grade of metamorphism most extensively reached by the mica schists. They closely resemble those recorded from Jimperding but differ in the more ragged form of the andalusite crystals, which have been changed by retrograde metamorphism into a shimmer aggregate of sericite (Knopf, 1931). In thin section the colourless sericitised andalusite porphyroblasts are seen to enclose diablastically numerous small blebs of quartz presumably picked up during rapid crystal growth. Small brown tourmaline crystals occasionally occur.

* The figures in parentheses refer to catalogued specimens in the General Collection at the Geology Department, University of Western Australia.

*Garnet-andalusite-mica schist,* a local development of the andalusite-mica schists in the south-east part of the Area is very similar to the occurrences at Goyamin Pool, north of the Lower Chittering Area. Heavy mineral fractions show abundant small pink garnets (0.5 mm. diameter) of a composition presumably close to almandine. They indicate the attainment of higher grades of metamorphism locally.

*Staurolite-mica schist* (?) was recorded along the eastern branch of Malkup Brook. It is a greyish brown, rather weathered, fissile rock, with an uneven surface due to the presence of small dark crystals which resemble staurolite. However in thin section the positive identification of this mineral as staurolite is impossible because of its complete sericitisation.

Besides those minerals common to the mica schists, there occur also a few small grains of brown tourmaline, some of which are somewhat rounded. This tourmaline may be of pneumatolytic origin (from the granite intrusions) or an original detrital constituent of the sediment.

*Sillimanite-mica schists* represent the highest grade of metamorphism attained in the pelitic sediments. The sillimanite forms fine needle like aggregates sometimes inclined to stellate arrangement. The silky lustre of these aggregates serves to identify sillimanite provisionally in the hand specimen. As a result of retrograde metamorphism the sillimanite has given rise to sericite. The sillimanite has formed from both biotite and muscovite but as the generation from biotite requires alumina from the muscovite (Tattam, 1929) it is considered that the latter mineral has been the main source of sillimanite. Quartz crystals, containing unoriented needles of sillimanite, are common.

(b) *Quartzites.*—The quartzites vary considerably as regards grain size and texture and both along and across the strike. Although composed predominantly of quartz many quartzites show the development of small colourless flakes of sericite or muscovite along bedding planes. In others the greenish mica, chrome muscovite is well developed. With the development of considerable quantities of mica the quartzites pass into quartz mica schists (section 40611).

In thin section the quartzites show a granoblastic mosaic of interlocking crenulated quartz grains, throughout which are scattered granules and scales of different minerals. The occurrence of several micas has been mentioned previously. In one section (40533) the greenish chrome muscovite is much darker in colour and has a distinct pleochroism $\alpha$ = bright green, $\beta = \gamma$ = blue green. This may possibly be due to a higher chromium content. The micas (chrome muscovite, muscovite and biotite) occur as flakes between the quartz grains where they are usually in parallel orientation or as small rod-like inclusions in the quartz. Diopside was noticed in several sections. The mineral was of a distinct brown colour in the hand specimens, particularly on slightly weathered surfaces, but microscopic examination of fragments and thin sections revealed the true pale green colour. Other optical properties were $\gamma \wedge c = 42°$; optical character + ve. The hornblende of some quartzites may be due to close contact with dolerite dykes. Minor constituents noted in the quartzites include epidote (section 40631) as small yellowish green pleochroic granules; zircon as small subhedral crystals; apatite as small colourless rods; rutile (section 40611) as small dark brownish red subhedral crystals; and magnetite, haematite and possibly chromite (found only in the chrome muscovite) as very small grains.

(c) *Jasper Bars.*—The rock is characterised by a number of well defined layers some of which are highly contorted and drag folded. The contorted portion 4 cm. wide (fig. 2) is composed of ten bands of quartz from 2 mm. to 4 mm. wide alternating with fairly narrow bands (2 mm. wide) of iron ore. This drag folded portion is bordered by a series of layers of very dark brownish highly weathered material 5 mm. wide, alternating with thin bands of iron ore 2 mm. wide. In some cases the iron ore is replaced by bands of idioblastic blue green amphibole.

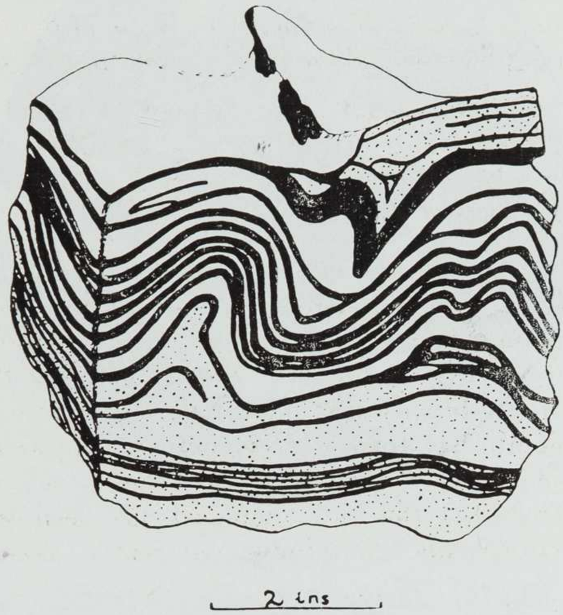


Fig. 2. *Jasper Bar*—Spec. (17521).—The quartz iron ore bands are represented in the centre of the figure bordered by amphibole iron ore bands (dotted), which contain dark bands of pure iron ore. The wide dark band between the quartz iron ore bands and the amphibole iron ore bands at the top, is composed of pure blue green amphibole.

In thin section the following minerals were recognised:—Quartz, iron ore, cummingtonite and a blue-green amphibole. The clear xenoblastic quartz crystals show undulose extinction, and are often present as inclusions in the iron ore, which occurs as irregular aggregates and grains frequently segregated into bands. A simple test with a magnet indicates that the greater part of the iron ore is magnetite. Its streak is brownish black. This colour is due to the magnetite being partly replaced by an iron sesquioxide. Elongated sections of the idioblastic blue-green amphibole show parallel cleavage and basal sections show typical amphibole cleavage. The optics of the amphibole are: Pleochroism $\alpha$ = yellow, $\beta$ = black, $\gamma$ = light blue; $\gamma \wedge c = 15°$; $\gamma > 1.706 > \alpha$. Inclusions are rare and the crystal faces are often stained with iron oxide. The blue-green amphibole is usually xenoblastic towards the cummingtonite, which shows both parallel and intersecting amphibole cleavage. The optical character of this variety of cummingtonite is —ve and the extinction $\gamma \wedge c = 10°$. Simple twinning is common and traces of inclusions of blue-green amphibole are often present. Other bands show the existence of a minute striation parallel to the basal plane. Where this is combined with the common prism cleavage a characteristic type of herring bone appearance is produced. The + ve optical character of this mineral which has $\gamma \wedge c = 16°$ and $\gamma = 1.67$, indicates a variety of cummingtonite with approximately 40 Mol.% $FeSiO_3$ (Winchell. 1927, p. 206). The — ve optical character of some types noted above may be due to the admixture of the actinolite molecule (Prider, 1938, p. 66).


Fig. 3. *Jasper Bar*—Section (40535).—Quartz iron ore bands. Shows banded nature of quartz and iron ore with small cummingtonite crystals projecting from the iron ore.

Under the microscope the different bands which can be recognised are:—

(1) Quartz-iron ore bands;

(2) Amphibole-iron ore bands which alternate with either,

(a) pure blue green amphibole bands;

(b) pure iron ore bands.

(1) (Fig. 3). The quartz bands are 1 mm. wide and alternate with iron ore bands 2 mm. wide. While the trend of the iron ore bands is fairly constant, their edges are frequently broken by inclusions of quartz. The regularity is also destroyed by the projection of cummingtonite crystals from the iron ore bands into the quartz bands. The unoriented cummingtonite crystals are in the form of small rods which possess a somewhat fibrous structure.

(2) The very highly weathered brownish bands occurring outside (1) above are composed mainly of amphibole and iron ore. The texture is granoblastic gneissic, the constituent minerals forming an interlocking equigranular mosaic. The cummingtonite crystals are never more than $\frac{1}{5}$ mm. long and often show patches of blue-green amphibole. The iron ore usually forms irregular granules and the crystals of blue-green amphibole are usually smaller than the cummingtonite crystals. Some sections show this layer to be composed almost entirely of cummingtonite, with only a few scattered crystals of blue-green amphibole and no iron ore.

(a) The boundary between the pure blue-green amphibole band and (2) above is well marked. The band is 4 mm. wide and is characterised by the development of large idioblastic crystals of blue-green amphibole (4 mm. x 2 mm.) to the exclusion of all other minerals (Fig. 4).

(b) The iron ore bands alternating with (2) above are essentially similar to the iron ore in (1) above.

Fig. 4. *Jasper Bar*—Section (40535), showing junction of large blue green hornblende band with an amphibole iron ore band which is composed of cummingtonite (dotted), blue green amphibole and iron ore.

## 2. Meta-Igneous.

These have been subdivided into:—

(a) Basic schists.

(b) Granite gneisses.

(a) *Basic schists* (*Hornblende schists*).—The basic schists are characterised by the presence of hornblende, felspar and a little quartz. The colour of the hand specimens vary from dark greenish black to black and the texture varies from schistose to massive. Epidote veins are common.

Under the microscope the following minerals were recognised:—Hornblende, oligoclase, quartz, orthoclase, diopside and accessory apatite, ilmenite, epidote, sphene and zircon. The form of the hornblende varies with the character of the rocks. It may be decussate; xenoblastic with poeciloblastic inclusions of quartz or in the form of ragged plates or fibrous stout prisms oriented parallel to the schistosity. The optics of the hornblende are pleochroism $\alpha$ = yellow green, $\beta$ = green, $\gamma$ = blue green; extinction $\gamma \wedge c = 20°$; $\gamma > 1.66 > \alpha$. Prider (1938, p. 45) notes that hornblendes from the Toodyay hornblende schists have $\beta$ 1.672, which is indicative of hornblende from epidiorites in the sillimanite zone. (Wiseman, 1934, p. 394). Both simple and multiple twinning occur and inclusions of xenoblastic quartz, granular diopside, epidote, sphene (with associated pleochroic haloes), are common. The dominant felspar is slightly turbid oligoclase, which shows albite and pericline twinning. In one instance (section 40592) inclusions of long acicular hornblende crystals were noticed. Quartz and orthoclase are subordinate and apatite, ilmenite, epidote, sphene and zircon occur as accessories. The mineralogical composition (volume %) is variable. Hornblende 60-80%, felspar 20-40%, quartz 5%.

Narrow bands and lenticles of diopside were recorded in some hornblende schists. This mineral forms greenish blue to colourless equidimensional crystals, with the rectangular prism cleavages well developed. Extinction is $\gamma \wedge c = 30°$. It is idioblastic towards the plagioclase and contains poikiloblastic inclusions of quartz and felspar.

In specimens from the contact of hornblende schist with granite the hornblende has been heavily chloritised and this may explain the occurrence of small patches of chlorite schist in the granite. The chlorite schists are hard, massive, distinctly foliated rocks, possessing in thin section a lepidoblastic structure due to the presence of long irregular frayed bands of colourless to dark green chlorite. Epidote occurs scattered throughout the rocks either as columnar crystals or granular aggregates. Quartz forms clear colourless xenoblastic crystals easily distinguishable from the sericitised albite.

(b) *Granite Gneisses.*—The granite gneisses may be subdivided into two groups according to the character of the felspar.

TABLE II.

*Micrometric Analysis of Granites and Granite Gneisses of Malkup Area. Mineral Percentage by Volume.*

| Mineral. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Quartz .. .. .. | 29.2 | 39.2 | 23.3 | 38.8 | 30.5 |
| Potash felspar .. .. | 35.8 | 27.8 | 40.5 | 44.8 | 9.8 |
| Plagioclase .. .. .. | 10.4 | 12.7 | 4.1 | 9.4 | 33.6 |
| Microperthite .. .. | 18.5 | 11.4 | 18.9 | 2.4 | .. |
| Myrmekite .. .. .. | 1.0 | .. | 1.8 | 0.6 | .. |
| Biotite .. .. .. | 4.7 | 7.6 | 4.8 | 2.2 | 25.9 |
| Magnetite .. .. .. | 0.4 | 1.3 | 5.4 | 0.2 | .. |
| Epidote .. .. .. | .. | .. | 1.2 | 1.6 | .. |
| Apatite .. .. .. | .. | .. | .. | .. | 0.2 |

1. Microcline granite—section 40586.
2. Microcline granite—section 40678.
3. Biotite-microcline-granite gneiss—section 40538.
4. Biotite-microcline-granite gneiss—section 40663.
5. Biotite-oligoclase-granite gneiss—section 40549.

(i) *Biotite-microcline-granite gneiss.*

*Augen gneiss.*—The texture is medium to fine grained and in thin section the structure is granoblastic gneissic. Microcline, orthoclase, quartz, plagioclase and biotite form the essential minerals and epidote, apatite, muscovite, chlorite, magnetite and ilmenite the accessories. Where the edges of the large cracked microcline plates are in contact with plagioclase, myrmekitic intergrowths are often developed. The microcline crystals also contain irregular inclusions of quartz and plagioclase. Quartz occurs in xenoblastic unstrained crystals sometimes elongated parallel to the banding. Oligoclase is usually less abundant than microcline and is present as rather large saussuritised and sericitised unoriented crystals. Biotite forms greenish brown deeply pleochroic crystals ( $\alpha$ = yellow brown, $\beta$ = $\gamma$ = brown) aligned in more or less definite bands parallel to the foliation. The crystals show sagenite webbing, as well as pleochroic haloes around zircon inclusions. Alteration to chlorite is common.

The mineralogical composition (volume %) of the rock by micrometric analysis is given in Table II., column 3.

*Banded acid gneisses.*—Mineralogically these rocks resemble the augen gneisses but differ in the more complete granulation of the augen.

Prider (1938, p. 52) has noted the occurrence of xenolithic bodies, of both igneous and sedimentary origin, in the augen gneisses of the Toodyay Area. The igneous xenoliths include schistose plagioclase amphibolites and hornblende schlieren. The sedimentary xenoliths are biotite granulites, which are considered to be developed from psammitic sediments. Only one of these rather rare xenoliths has been noted in the augen gneiss of the Malkup Area. As these rocks though are undoubtedly continuous with those of the Toodyay Area, they must have the same origin.

*Fluxion gneiss.*—In thin section the fluxion gneiss differs from the augen gneiss in that the quartz crystals frequently show undulose extinction. The twin lamellae of the plagioclase crystals (oligoclase andesine) are also highly strained. (Incidentally the presence of myrmekite along with the deformed plagioclase indicates that it was formed after the shearing.) Further the dominant felspar is usually orthoclase showing alteration to microcline. This is recognised by the development of cross hatched twinning along the borders of the orthoclase crystals. There has been an increase in volume accompanying the change from orthoclase to microcline as revealed by undulose extinction and phantom twinning in central parts of the crystals. (Alling, 1923, pp. 283-305 and pp. 353-375.)

The mineralogical composition (volume %) of the rock by micrometric analysis is given in Table II., column 4. This rock type grades through a crushed microcline granite (section 40613) to the typical microcline granite of the western part of the Area.

(ii) *Biotite-oligoclase-granite gneiss.*—The rock is light to medium grey in colour, well banded, and is cut by later aplites and pegmatites. Where finely banded the structure may become schistose.

In thin section the texture is granoblastic gneissic. The minerals present are oligoclase, quartz and biotite, with apatite, sphene and ilmenite as accessories. Oligoclase occurs as elongated subhedral grains oriented parallel to the banding. The crystals are turbid and many show zonal arrangement of inclusions, as well as blebs of quartz. Quartz, like oligoclase, is elongated parallel to the banding. Biotite, which occurs in bands, frequently possesses a clotted character indicating that it is probably a remnant of some earlier rock picked up by the intrusive granite magma, i.e., these clots of biotite may be micro-xenoliths. The biotite has frequently been altered to penninite.

The mineralogical composition (volume %) by micrometric analysis is given in Table II., column 5.

(c) *Xenolithic bodies in both Augen and Fluxion Gneisses.*

*Pyroxene-amphibole gneiss.*—This rock type only occurs in two localities; firstly as a narrow band in the augen gneiss and secondly as a few scattered boulders in the north-eastern part of the Area, the main rock type of which is a fluxion gneiss.

They are hard, massive, greenish rocks, slightly banded due to the alternation of quartz with greenish hornblende and diopside. Pyrite is present.

In thin section the texture is granoblastic gneissic with the minerals tending to form interlocking mosaics. Minerals present are quartz, microcline, orthoclase, plagioclase, hornblende and diopside with accessory pleochroic sphene, needles of apatite and zircon. The quartz is elongated parallel to the banding. Orthoclase forms anhedral plates frequently showing inversion to microcline with accompanying undulose extinction. Inclusions of rounded quartz blebs, apatite rods, diopside and hornblende crystals are common. The potash felspar is almost invariably turbid. Hornblende occurs as irregular plates and fibrous rods elongated parallel to the banding. The pleochroism is $\alpha =$ yellow green, $\beta =$ green, $\gamma =$ blue green, and the extinction $\gamma \wedge c = 23°$. A few idioblastic crystals of brownish hornblende occur. The hornblende is intimately associated with equidimensional grains of a colourless to green pyroxene which has extinction $\gamma \wedge c = 40°$.

(d) *Xenoliths and Hybridisation of the Fluxion Gneiss.*

The various stages in the progressive assimilation of basic rocks (mineralogically identical with the basic schists) by the microcline granite magma may be summarised as follows:—

Hybridised Types.

Basic Schist → { Melanocratic → Mesoratic → Leucoratic } → Fluxion Gneiss.

Within the hybridised types there are two distinct groups:—

(i) Rocks with granoblastic gneissic structure.

(ii) Rocks with granitic structure.

The basic schist and fluxion gneiss have been previously described (p. 153 and p. 155). The hybrid types are:—

(1) *Rocks with granoblastic gneissic structures.*—These may be called hornblende gneisses and they vary from melanocratic to leucocratic. The melanocratic hornblende gneiss which differs from the basic schist only in texture, contains hornblende, oligoclase and quartz, with accessory magnetite and apatite. The hornblende forms large porphyroblasts usually hypidioblastic with typical prism cleavages. The pleochroism is $\alpha =$ yellow green, $\beta =$ dark green, $\gamma =$ blue green, and the extinction is $\gamma \wedge c = 16°$. The form and optical properties of the amphibole are constant throughout the series. With an increase in felspar content and a corresponding decrease in the hornblende content the melanocratic hornblende gneisses pass into mesocratic hornblende gneisses. The increase in the felspar content is due to the addition of alkali felspar from the magma. The decrease in hornblende content is due to the instability of that mineral under the new conditions. Its alteration products are biotite, chlorite, epidote and sphene. The biotite forms irregular, ragged, weakly pleochroic flakes moulded on the hornblende. Patches of faintly pleochroic pale green chlorite ($\beta = 1.625$), which contain inclusions of lozenge shaped crystals of sphene and colourless to yellow granules of feebly pleochroic epidote, have resulted from the alteration of biotite. The oligoclase felspar is also unstable and has been replaced by a mat of sericite and granular epidote. The passage from mesocratic hornblende gneisses to leucocratic hornblende gneisses is a result of further increased felspar content and corresponding

reduced hornblende content The reaction products from the alternation of hornblende and oligoclase are further increased. With the appearance of microcline, complete assimilation of the hornblende, and re-adjustment of the reaction products the leucocratic hornblende gneisses grade into the normal fluxion gneiss.

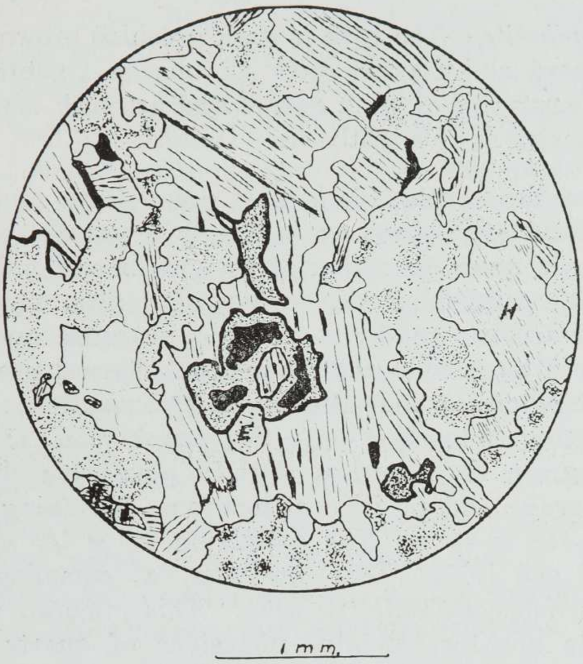


Fig. 5. *Hybrid*—Section (40643), showing crystals of sphene moulded on iron ore and containing chlorite inclusions which are in optical continuity with the chlorite in which the sphene is embedded. Epidote (E) enclosed in chlorite, hornblende (H) altering to chlorite, saussuritised felspar and quartz comprise the remainder of the slide.

(ii) *Rocks with Granitic Structure.*—Mineralogically, the hybridisation of the fluxion gneiss in the extreme eastern part of the Area is almost identical with (1) above. The rocks produced, however, show a complete lack of gneissic banding, basic segregations and clots. They are predominantly even grained, holocrystalline and uniform textured. However, the twin lamellae of many of the felspar crystals are often distorted and quartz crystals show undulose extinction. The occurrence of clinozoisite as euhedral crystals protruding from heavily saussuritised felspar (section 40640), and of sphene rims around iron ores (Fig. 5) are minor noteworthy mineralogical differences from the hornblende gneisses. As the fluxion gneiss is approached the hornblende content decreases, biotite increases and microcline replaces plagioclase.

(e) *Xenoliths in the Biotite-Oligoclase-Granite Gneiss.*

*Biotite-plagioclase-granulite.*—In thin section, biotite, the only ferromagnesian mineral, is seen to make up from 30-40% of the rock. The irregular, rarely chloritised plates show a pleochroism $\beta = \gamma =$ black, $\alpha =$ yellow brown. Plagioclase, the dominant felspar, forms about 35% of the rock. Clear colourless quartz crystals, which contain numerous rod-like inclusions of apatite oriented parallel to the gneissic banding, form an interlocking mosaic with the xenoblastic felspar crystals. Accessories include a little magnetite, granular sphene, and zircon with its associated pleochroic haloes when included in biotite.

### 3.—Doubtful Origin.

*Garnet Amphibolite.*—The rock is dark greenish brown in colour, rather coarse grained, hard and massive with an uneven fracture and high S.G. (= 3.13). It is composed of pink garnet and greenish black amphibole. As a result of weathering it is slightly iron stained.

In thin section the structure is in part granoblastic and in part nematoblastic. The nematoblastic structure is due to a parallel orientation of the amphibole. Garnets occur in rather large equidimensional crystals (up to 5 mm. across) with poikiloblastic inclusions of quartz, amphibole and magnetite. Their surface has rather a pitted appearance and they are often altered along cracks to chlorite and magnetite. Garnet pseudomorphs after amphibole (cummingtonite) indicate the later formation of garnet with a composition very similar to that of the amphibole. Cummingtonite is present as light green to colourless slightly pleochroic crystals, generally showing good cleavage and positive elongation. Twinning is common and the optical character is +ve. The extinction is $\gamma \wedge c = 18°$ and $\gamma$ lies between 1.686 and 1.691. This indicates a cummingtonite with 70 Mol. % $FeSiO_3$ (Winchell, 1927, p. 206). This mineral, which may form parallel or radiate growths, contains inclusions of quartz and colourless zircon. Its replacement by garnet has already been mentioned. Quartz occurs in clear xenoblastic interstitial crystals. Accessories include colourless rounded apatite, light brownish crystals of sphene and a little magnetite and chlorite.

## *B.—The Later Igneous Intrusions.*

### 1.—Acid Intrusives.

(a) *Microcline Granite.*—The microcline granite, which occurs mainly in the western part of the Area, is a fine to medium grained, seriate, leucocratic, granitic textured rock. In composition it is very acid with a rather low percentage of ferromagnesians. The S.G. averages 2.63.

In thin section the following minerals were recognised:—

Quartz—abundant in all slides as anhedral, slightly cracked crystals of variable grain size. Interstitial growths occur with the felspars.

Felspars—Microcline and orthoclase are abundant in slightly turbid hypidiomorphic crystals. The turbidity is due to kaolinisation and sericitisation. Plates often show embayed edges carrying myrmekite and quartz. Oligoclase is present in most sections as saussuritised euhedral to subhedral crystals. The zoned arrangement of alteration products indicates a zoning in which the centres of the crystals are composed of a more basic oligoclase than the outside.

Microperthite is common in the granites. It is "streaky perthite" (Anderson, 1937, p. 60)—veinlets of albite crossing potash felspar. There is no twinning in the albite and the intergrowth trends at right angles to the cleavage of the orthoclase.

Myrmekite is seen as wart-like intergrowths in orthoclase, microcline and microperthite. Its occurrence in microperthite produces an intergrowth similar to Geyer's myrmekite perthite (Sederholm, 1916).

Injection micropegmatite is particularly abundant and passes through all types of felspar. The inclination to the orthoclase cleavage is, on the average, 110°, but it often forms irregular stringers. True micropegmatite is not very common but does occur (section 40589). The felspar is very cloudy and the quartz of the intergrowth is seen to be in crystallographic continuity with the quartz crystal upon which it has grown.

Biotite forms characteristic ragged crystals with pleochroism $\gamma$ = dark brown, $\alpha$ = yellow. It is often changed to synantetic chlorite which is pleochroic from yellow green to dark green. Inclusions of zircon, with strong pleochroic haloes, occur both in biotite and chlorite. Sagenite webbing, due to dark needle like inclusions of rutile arranged in an interlaced web structure, is frequently present. Sagenite webbing has been recorded in the granites of Chittering (Miles, 1938, p. 28), and Upper Swan Area (Fletcher and Hobson, 1931, p. 28). It is probably due to heating of original biotite with the separation from it of its titanium content in the form of rutile. The sagenite webbing is sometimes found remaining in synantetic chlorite.

Biotite is often moulded on yellow green anhedral epidote crystals which are pleochroic from yellow green to colourless. Most of the epidote appears to have been introduced as later veinlets, as for example section (40683) where the crystals are columnar and perfectly euhedral.

Muscovite is rare but where present is almost invariably associated with biotite. In section (40683) it is moulded on and included in plagioclase crystals parallel to the cleavage. Inclusions of epidote are common.

Sphene is a variable constituent forming euhedral to subhedral, brownish, non pleochroic, highly refracting crystals. It frequently contains a core of ilmenite and the smaller crystals are often moulded on either biotite or chlorite.

Accessories include slender acicular prisms and stumpy basal sections of apatite, crystals of zircon and rutile embedded in biotite and occasional grains of iron ore. Ilmenite when present is invariably surrounded by leucoxene or sphene.

(b) *Aplites and Associated Pegmatites.*—These intrude the metamorphics and the granite. Macroscopically the pegmatites consist of coarse textured crystalline quartz and alkaline felspar. The felspar crystals are as large as 6 inches long and 2 inches wide, but the quartz crystals are usually smaller. Dark segregations are abundant, one being 3/10 inch in diameter and surrounded by a rim of limonite.

The aplites are light coloured, fine grained, equigranular granitic rocks bordered by pegmatitic phases. They consist of quartz, alkaline felspar, plagioclase and a little biotite and muscovite.

In thin section the texture is fine grained granitic. Clear colourless anhedral quartz crystals averaging 0.1 mm. in diameter form an interlocking mosaic with the felspar. Both microcline and orthoclase occur abundantly in slightly cloudy sericitised subhedral plates. Oligoclase is subordinate in cloudy, slightly saussuritised hypidiomorphic plates. Microperthitic intergrowths, both of streaky and of patchy types are common and they frequently show undulose extinction. Biotite, usually chloritised, occurs as an accessory.

Muscovite forms subhedral plates idiomorphic towards both felspar and quartz. Garnet occurs in section (40605) as highly refracting, slightly cloudy, colourless isotropic grains.

(c) *Quartz Veins.*—Small quartz veins clearly cutting across the metamorphics and through the granite and gneiss are of frequent occurrence. Very few large veins have been noted. The relation of the quartz veins to the pegmatite aplite intrusions is not clearly seen but some of the smaller veins seem to have preceded the aplites and pegmatites.

(d) *Felspar Porphyries.*—The felspar porphyries form narrow dykes which appear to be cut by both the basic intrusives and the shear zone. In hand specimen they are light greyish blue, fine grained, massive rocks.

The porphyritic texture is revealed in thin sections where phenocrysts of felspar and quartz are embedded in a fine grained ground mass. The felspar occurs in highly altered subhedral to euhedral crystals. Orthoclase, showing carlsbad twinning and extensive kaolinisation and sericitisation, is usually dominant over plagioclase but in some slides this is reversed. The plagioclase (oligoclase) is often almost completely saussuritised and kaolinised. Quartz phenocrysts occur as clear anhedral to subhedral crystals up to 1 mm. in diameter. Biotite, which forms very ragged flakes altering to synantetic chlorite, shows no marked distinction between phenocrysts and ground mass.

A microcrystalline, allotriomorphic, interlocking mosaic of quartz, orthoclase, plagioclase and biotite constitutes the ground mass. Secondary minerals include much epidote mostly of later introduction but also derived in part from the saussuritisation of plagioclase felspar. Sericite derived from the potash felspar is also abundant.

In one specimen phenocrysts of felspar up to 3 mm. in diameter were recognised in a light brownish ground mass which is cut by numerous irregular dark green stringers.

With the exception of the stringers the rock is in thin section essentially the same as the more normal felspar porphyries. The impression obtained from a study of the rock in thin section, is that it has been severely brecciated and the cracks have later been healed by veinlets of epidote. The character of the biotite and chlorite also call for some comment. The chlorite occupies many irregular stringers and patches which often contain small brownish green laths of biotite. These resemble xenoliths which have been picked up by the porphyry, incompletely digested and later stretched out into stringers.

## 2.—Basic Intrusives.

The basic intrusives have been subdivided into—

(a) Dolerites.

(b) Quartz Dolerites.

(c) Epidiorites.

These differences may be correlated with variations in the proportion of end stage quartz residuum and the degree of deuteric alteration of the pyroxene. (See Table III.)

TABLE III.

*Micrometric Analyses of Basic Intrusives from Malkup Area.*

*Mineral Percentage by Volume.*

| Mineral. | 1 | 2 | 3 |
|---|---|---|---|
| Plagioclase .. .. .. | 44.4 | 36.1 | 37.3 |
| Augite .. .. .. .. | 39.3 | 34.8 | .. |
| Uralite .. .. .. .. | 5.1 | 19.8 | 29.5 |
| Hornblende .. .. .. | 1.4 | .. | 9.9 |
| Chlorite .. .. .. | 1.9 | 2.7 | 5.8 |
| Iron Ores .. .. .. | 7.1 | 5.8 | 5.6 |
| Biotite .. .. .. .. | 0.8 | .. | .. |
| Pyrite .. .. .. .. | .. | 0.9 | .. |
| Apatite .. .. .. .. | .. | .. | 2.0 |
| Quartz .. .. .. .. | .. | Present | 9.9 |

1. Dolerite—section 40649.
2. Quartz Dolerite—section 40570.
3. Epidiorite—section 40574.

(*a*) & (*b*) *Dolerites and Quartz Dolerites* may be conveniently treated together. They are melanocratic, massive rocks, generally equigranular but frequently showing small veins and segregations of a much coarser pegmatitic phase which is mineralogically the same as the rest of the rock. Black augite, cloudy felspar and occasional pyrite, are the only mine.als recognisable in the hand specimen.

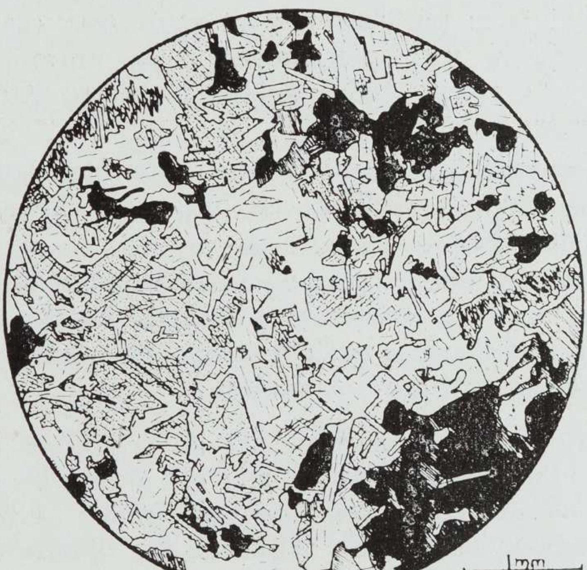


Fig. 6. *Dolerite*—Section (40649), showing typical ophitic relation between felspar and augite. The iron ore is surrounded by a rim of chlorite.

In thin section ophitic texture is always well developed (Fig. 6). The constituent minerals include pyroxene, plagioclase felspar, quartz, iron ores, amphibole, biotite and accessories. Pyroxene occurs as colourless to light brown, non pleochroic, subhedral to euhedral crystals. Cleavage is usually well developed in one direction but sometimes in two directions at right angles to each other. Schiller structure has often been noted. The extinction angles vary, *e.g.* $\gamma \wedge c = 0° - 45°$. In sections with oblique extinction a biaxial figure is obtained but those with straight extinction give a pseudo-uniaxial figure. The optical character is always —ve. This indicates a monoclinic pyroxene with small axial angle such as enstatite augite or pigeonite (Barth, 1931). Several dolerites showed the cleavages of this pyroxene arranged in a more or less circular fashion with incipient fracturing. These crystals are built up of segments which extinguish separately. While the pyroxene crystals in the dolerites are fairly fresh, in the quartz dolerites alteration to fibrous green uralite is common. All stages of alteration are found and often this uralitisation is followed by chloritisation.

Plagioclase occurs in long columnar and lath shaped crystals ophitically intergrown with the pyroxene. Fine lamellae and simple carlsbad twinning are common and extinctions normal to the plane of the albite twin lamellae indicate labradorite. Saussuritisation and kaolinisation are common. Aborescent chlorite (from alteration of uralite) is often found along cleavages and fractures in the plagioclase.

Quartz is absent from the dolerites but forms up to 5% in the average quartz dolerite. It occurs either interstitially or as clear allotriomorphic crystals which contain apatite inclusions.

Iron ores take the form of large "skeletal" crystals of ilmenite which show alteration to leucoxene along crystallographic axes. Where in contact with felspar they are usually rimmed with greenish chlorite, and occasionally with synantetic sphene. Magnetite and pyrite are also present.

Amphibole.—Two varieties are present (1) the pale green fibrous uralite which has resulted from the alteration of pyroxene; (2) a brownish well crystallised hornblende with pleochroism $\alpha$ = brownish yellow, $\beta$ = brownish green, $\gamma$ = green. Although seen associated with uralite the hornblende has a primary appearance.

Biotite is present in the quartz dolerites as small irregular flakes frequently exhibiting sagenite webbing. It has a pleochroism $\beta = \gamma$ = dark brown, $\alpha$ = straw yellow.

Accessories include apatite as long needles and rods which show cross fractures; zircon, with its associated pleochroic haloes, as inclusions in amphibole, biotite and chlorite; epidote as narrow veinlets and as an alteration product of the saussuritised plagioclase.

(*c*) *Epidiorites.* The epidiorites have all originated from dolerites by deuteric processes the results of which have not always been the same. They differ from the dolerites in the complete uralitisation of the augite and the comparative abundance of quartz. Although the ophitic texture is usually lost they are essentially the end members of a series from dolerites to quartz dolerites that is, a series of increasing acidity.

In another group of meta-dolerites or epidiorites the deuteric processes are probably due to some late stage magmatic change where the volatiles and gases played an important role. These rocks, being apparently only phases of the basic intrusives, have a limited distribution.

In hand specimen they are massive, uniform textured rocks sometimes tending to show a linear parallelism of hornblende rods. Other minerals present include felspar and a little pyrite.

In thin section the texture is holocrystalline allotriomorphic. Amphibole porphyroblasts form anhedral plates with "sieve" structure due to microscopic inclusions of quartz. The twinning developed is both simple and lamellar and the pleochroism of most varieties is $\alpha$ = yellow green, $\beta$ = dark green, $\gamma$ = blue green. The felspar is generally completely altered to granular epidote, zoisite, sericite and fibrous chlorite. Although actual identification is difficult the felspar appears to be a sodic plagioclase. Some sections show typical anhedral crystals of quartz with acicular inclusions of apatite. The felspar also contains similar apatite inclusions. Irregular crystals of magnetite and leucoxenised ilmenite form the iron ores.

(*d*) *Xenoliths in the Quartz Dolerites.* Two types of basic intrusives rather different from the above have been observed. The first (17574, section 40584) was a basic dyke cutting through granite west of the shear zone on the northern side of the Avon River. From a distance it had a peculiar speckled appearance and on close examination this was found to be due to the presence of large angular slightly pinkish "minerals" scattered liberally through the rock. The size of these fragments ranges up to 1½ inches x 1 inch. They are generally quite idiomorphic although occasionally aggregates of fragments are seen as though partially digested by the magma. A section cut across the contact of an idiomorphic crystal with the dark fine grained "ground mass" showed the latter to be composed of epidiorite with one or two small remnants of augite. The uralite is largely altered to chlorite and sometimes subophitically encloses a little plagioclase. Interstitial quartz and micropegmatite are fairly abundant; apatite and ilmenite are accessory. The idiomorphic crystal was composed almost entirely of a cloudy mass of saussurite (zoisite and sericite). Stillwell has recorded similar occurrences (Stillwell 1911-14, pp. 48-55). He regarded the idiomorphic crystals as xenoliths in the dyke, calling them the composite type of metaxenolith. They are best explained as metamorphosed cognate xenoliths derived from the decomposition of felspar. The marked angularity of some of the xenoliths, he says, shows that they have not travelled far along the dyke channel. They must have come from the magma chamber and therefore the present surface must be very close to the original magma reservoir. The very perfect shape of these idiomorphic crystals offers the additional possibility that they may be original phenocrysts which have been later metamorphosed along with the enclosing rock.

Somewhat different rocks but possibly of similar origin were noted about a quarter of a mile north of the mouth of Malkup Brook (17578, section 40594). A similar rock occurs near Toodyay but has not been described. The Malkup type, which had no definite outcrop, has a very mottled appearance due to irregular elongated light greenish white patches scattered through a dark fine grained slightly schistose hornblendic matrix.

In thin section the equidimensional hornblende crystals of this ground mass are hypidioblastic and show a pleochroism $\alpha$ = yellow green, $\gamma$ = blue green. The extinction is $\gamma \wedge c = 14°$. Other constituents include completely saussuritised felspar, a little xenoblastic quartz and small grains of ilmenite. Sphene rims often surround the ilmenite.

The "phenocrysts" are most irregular in form and size, the largest being 1 cm. x 2 cm. In thin section they are seen to be completely replaced by a granular aggregate of epidote and zoisite with a little quartz. There is now nothing to suggest whether they are original phenocrysts in a dolerite dyke which has been metamorphosed or whether they are xenoliths of felspar which have been saussuritised by a basic magma. The authors are inclined to take the view that all the xenoliths in the quartz dolerites described in this section are metamorphosed cognate xenoliths.

(e) *Associated Granophyres.*—In hand specimen the granophyres are dark grey, massive, slightly porphyritic rocks. The phenocrysts are rather equidimensional crystals of quartz and felspar embedded in a fine grained matrix of quartz, felspar and biotite.

In thin section the porphyritic structure visible in the hand specimen is confirmed. The quartz phenocrysts occur in clear anhedral to subhedral somewhat fractured crystals which contain inclusions of the ground mass. The felspar phenocrysts, of which orthoclase is more common than plagioclase, are kaolinised and saussuritised. The borders of quartz crystals often possess rims of hornblende and biotite, particularly biotite which forms ragged chloritised crystals. Epidote occurs in yellowish green slightly pleochroic aggregates.

Practically the whole base of the rock is composed of a micropegmatitic intergrowth of quartz and orthoclase. This intergrowth forms a framework around the phenocrysts. In section (40628) there is a slight development of microspherulitic structure.

*C.—Later Rocks.*

### 1. Cataclasite.

The field appearance of the shear zone which runs along the western margin of Malkup Area is extremely varied. The edges are composed of granite which has been extensively injected by vein quartz. The centre is composed of quartz and limonitic material.

A section was made of a hard massive type from the centre in which the quartz was in the form of elongated lenses separated by thin bands of limonitic material. A type of palimpset structure was revealed in which larger quartz relicts were surrounded by a mass of granulated quartz. These more or less parallel oriented elongated relicts are extremely crushed and granulated. The surrounding quartz forms a microcrystalline mosaic of allotriomorphic grains. Iron ore occurs in bands throughout the rock, parallel to the elongation of the quartz relicts. The rock may be described as a cataclasite.

### 2. The Duricrust.

The extent of the duricrust, which is generally referred to in Western Australia as laterite, has already been mentioned. It has been observed lying above (and so is formed from) practically all the rock types found in the Area. In the south-east part of the Area where the duricrust covers the mica schists and quartzites two or possibly three types occur. On one little knoll bounded by breakaways, the laterite has obviously been derived from quartzite. Numerous nodules of quartzite, usually rounded and about three inches to four inches across, are studded through a very quartose ferruginous matrix. A similar occurrence has been noted in the north-west part of the Area but, in this locality, the bedding of the quartzite can still often be seen.

Just east of the small knoll mentioned above, a mica schist has been extensively laterised but it still to some extent preserves its schistose structure. It is purplish in colour and contains white streaks with a silky lustre, which may have been sillimanite. A little farther west, in the granite about two or three chains from the contact of the granite with the mica schists and quartzites, a banded laterite has been recorded. It has bands, rather constant in width (between 1/16 inch and 1/8 inch) which anastomose leaving long narrow cavities. The bands are redder in colour than the ordinary laterite (resembling ochre) and they are extremely fine grained. The cavities however show the yellow colour of limonite.

The laterite formed over the granite and gneisses north of the Avon, is the pisolitic variety typical of the Darling Ranges (Simpson, 1912 and Clarke, 1919). Specimens were obtained from the centre of the area for future estimation of the iron and aluminium content. In the north-west part of the Area where the laterite has formed above the aplite and banded gneiss complex, a rather pretty "rose-bud" variety is found. Being essentially of the pisolitic type it shows well formed concretions around a kernel of quartz grains.

### 3. Talus Slopes.

Quartzites in particular have often formed steep talus slopes which frequently tend to cover up the mica schist bands. In several regions east of Munnapin Brook the quartzite talus slopes have formed banks up to 20 feet high even though the quartzite outcrop is quite some distance away. None of the slopes have been consolidated and hence they are extremely difficult to climb. The talus slopes of the sheer zone are very similar to these quartzite talus slopes.

### 4. Alluvium.

Mention has already been made of the presence of alluvium along the flood plain of the Avon River and at various places along its tributaries. The deposits of alluvium, at the mouths of the tributaries of the Avon are due to flooding during winter when the Avon dams back the waters of its tributaries. The greatest quantity of alluvium has been deposited by Munnapin Brook, which now meanders through a flood plain.

## V.—THE TYPE OF METAMORPHISM AND ORIGIN OF THE ROCKS.

In the absence of chemical analyses of the rocks of the Malkup Area, field evidence and mineralogical characteristics are the only available criteria of the nature of the original rocks.

### *A.—Meta-Sediments.*

### 1.—Quartzites.

Field evidence shows (a) a bedded appearance and (b) a highly siliceous composition.

Microscopical evidence shows (a) a general absence of cataclastic structure indicating recrystallisation and (b) the presence of oriented mica rods.

The field evidence clearly indicates a sedimentary origin for these rocks. They were deposited as sandstones, mostly very pure but in places containing slight impurities. Under the influence of pressure, acting vertically downwards on the beds, so that the mica flakes crystallised normal to the impressed force, the sediments were converted into the bedded quartzites now found. The presence of such minerals as epidote and diopside indicates than impurities of a calcareous nature were occasionally present. The metamorphism must have taken place in a region where recrystallisation was the dominant force.

### 2.—Mica Schists.

Field evidence shows that the mica schists are conformable with the quartzites which are regarded as of sedimentary origin.

The mineralogical composition of these schists which carry sillimanite, staurolite (?), garnet, andalusite, muscovite, biotite, chlorite and sericite, is consistent with that of a metamorphosed pelitic sediment (Tilley, 1926). Richness in alumina is the salient chemical characteristic of these rocks, the progressive metamorphism of which produces, at a certain zone, those aluminous silicates so highly characteristic of meta-sediments (Harker, 1932).

The metamorphism, judging by the minerals produced, must have been predominantly of a thermal character.

In the south-east part of the Area the mica schists sometimes become raher sandy and may even pass, without break, into quartzites.

### 3.—Jasper Bars.

The apparent bedded appearance and well marked banding in these rocks is indicative of an origin from sedimentary bedded iron ores. Owing to the absence of chemical analyses, there is very little evidence as to the exact nature of the original sediment. According to the minerals present, it appears to have been a rock composed of bands of limonite, chert and (Fe, Mg) carbonates.

The first stage of metamorphism would be the loss of $CO_2$ from the carbonates, the metallic ions still being retained. With increasing metamorphism these have reacted with silica to form cummingtonite. At the same time the reaction limonite $\rightarrow$ haematite $\rightarrow$ magnetite has been steadily proceeding. The production of magnetite would mark the attainment of a high grade of metamorphism. This is borne out by the production of cummingtonite. As a result of retrogressive metamorphism the magnetite is now partly replaced by an iron sesquioxide.

The production of blue-green amphibole requires a certain amount of argillaceous material to be present in the original sediment.

The position of this rock in the field (bordering on the intrusive granite on one side and on the mica schist on the other) and the complete lack of orientation of the amphibole, both indicate its formation under thermal metamorphic conditions.

## *B.—Meta Igneous.*

### 1.—Basic Schists.

The main points to be considered in connection with the origin of the hornblende schists are:—

(a) bedded arrangements in the field;

(b) presence of schistose structure, and absence of cataclastic effects in thin sections;

(c) the refractive index of the hornblende ( $\gamma >$ 1.66 $> \alpha$ ) is indicative of hornblende from epidiorites in the sillimanite zone (Wiseman, 1934, p. 394);

(d) the occurrence of diopside lenses and bands in the otherwise extremely uniform rock type. Harker (1932, p. 284) records the occurrence of colourless diopside in the more highly metamorphosed epidiorites at Beltcraig near Banchory.

They appear therefore to be original sills or flows of basaltic composition which have been folded with the metasedimentary series during the period of orogenesis.

Prider (1938, p. 45) notes that in the Toodyay area the hornblende schists in their chemical composition are normal igneous rocks, such as would result from the crystallisation of a quartz dolerite magma.

### 2.—Granite Gneisses.

(a) Biotite—Microcline—Granite—Gneiss.

*Augen gneiss.* Field evidence shows that (1) it is apparently interbedded with quartzites of supposed sedimentary origin and (2) it has a uniform texture and composition along the strike.

Microscopical evidence shows (1) protoclastic structures rather than cataclastic (2) a composition not essentially different from a microcline granite (see micrometric analyses, Table II., column 3) and (3) the frequent occurrence of myrmekite.

The evidence permits of three interpretations (a) a gneiss of sedimentary origin (b) a granite sill (c) contemporaneous acid flows.

The protoclastic structure of the microcline augen has already been mentioned. Quartz crystals show orientation parallel to the gneissosity, without peripheral granulation and with slight development only of undulose extinction. There are two possibilities (a) the quartz has recrystallised from original crushed grains under tectonic activity (b) it has crystallised after the formation of the augen structure.

Prider (1938, p. 49) has made a fabric analysis of the quartz in a fine, even grained granite gneiss (from Toodyay) showing this marked elongation of unstrained quartz grains. After measurement of 200 grains he found no apparent concentration of the optic axes in any direction. A well marked fabric was obtained by him for several of the quartzites overlying the augen gneiss. He considered that the complete absence of any girdle in the diagram for the gneiss indicated that the quartz was of post tectonic crystallisation. Since the augen gneiss of Malkup Area is continuous with the Toodyay granite gneiss, it would appear that the former is a biotite-microcline-granite gneiss formed from a porphyritic microcline granite magma. When the microcline crystals had separated out the magma was injected as a sill into the quartzite. The beds beneath this sill, however, have not been observed. The microcline crystals were granulated with the production of protoclastic structures, and the quartz crystals crystallised after the main tectonic movements had ceased. The banded biotite-microcline-granite gneiss represents a more complete granulation of the microcline augen in the augen gneiss.

*Fluxion gneiss.* This gneiss is essentially of the same mineral composition as the augen gneiss. It differs in being finer grained, in showing complete absence of augen of microcline with peripheral granulation, and in having a faint linear parallelism due to the orientation of biotite flakes. In the field, it takes the form of a bathylithic intrusion, being essentially massive and unstratified. Its period of intrusion would apparently have been after the emplacement of the augen gneiss, but before the crystallisation of the quartz in the augen gneiss. During this period tectonic forces were still in operation with the resultant production of the gneissic structure.

(*b*) *Biotite-Oligoclase Granite Gneiss.* At present the exact relationship of this granite gneiss to (a) is not known. Where it occurs as patches in the biotite-microcline-granite gneiss it appears (Prider 1938 p. 61) that it could be the result of crystallisation of the residuum squeezed off from the earlier formed microcline. However this relationship does not hold where a similar rock type is contained as xenoliths in the more normal microcline granite.

### 3.—The Origin of the Xenoliths and Hybrids in the Fluxion Gneiss.

The progressive stages of incorporation of basic material by the gneissic granite magma have been treated elsewhere. The character of this basic material is seen to be almost identical with the basic schist (plagioclase amphibolite) which is believed to be a sillimanite zone epidiorite, with an original composition of a quartz dolerite. The reactions in this progressive assimilation have been summarised by Brammall (1936. p. 622) (augite) ⟶ hornblende ⟶ biotite ⟶ chlorite. This alteration evolves epidote and a coloured variety of sphene. He notes that the Ca.-atoms trapped in the sphene and the (Al, Fe''')-atoms required for the transformation augite ⟶ biotite could both be products of some change affecting the lime rich felspars.

During this progressive assimilation of the basic igneous rock and reciprocal hybridisation of the granite gneiss, differential movement has been proceeding with the production of a gneissic banding. This can still be included under the category of primary fluxion structure (Harker, 1932, p. 301), *i.e.*, the hornblende gneisses are actually hornblende granite gneisses.

The production of the hybrid rock type in the eastern section of the area appears to be due to some similar process. Here the absence of gneissic structures indicates lessened tectonic activity with the production of more normal rock types. The assimilation of these solidified basic igneous rocks by the granite magma may be likened to the processes of contrasted differentiation as expressed by Nockolds (1934, p. 37) where intermediate rock types may be produced by the reaction of solid basic igneous rock with an acid aplogranite magma. As to whether these basic igneous rocks have solidified from the same magma that later produced the acid residuum by a process of contrasted differentiation, there is no definite evidence, but the hybridisation effects are similar to those which would be expected under such conditions.

Pyroxene amphibole gneiss, which is found as xenoliths in both the fluxion and augen gneiss, appears to represent bands of metamorphosed impure argillaceous limestones.

The biotite granulite xenoliths in the biotite—oligoclase—granite gneiss seem to represent psammitic types of sediments.

### *C. Doubtful Origin.*

*Garnet amphibolite.*—Field evidence shows that it is conformable with the mica schists. Microscopical evidence shows that in composition the minerals are probably Fe, Mg, Al, silicates. The evidence indicates that the garnet amphibolite was either a sill or a sediment conformable with the mica schists and quartzites.

As a sill it would have been injected at depth into heated sediments, for these show no contact metamorphic effects. To be in keeping with the present composition of the rock such a sill would have had the composition of a pyroxenite. Under metamorphism with relatively high shearing stress amphibolitisation would have altered the pyroxene completely to cummingtonite. The effect of succeeding load metamorphism would be to replace the amphibole by a garnet which has partly taken on the form of the radiating amphibole aggregates. The composition of the garnet corresponding to that of the amphibole is between pyrope and almandine.

It is possible that the garnet amphibolite is a meta-sediment derived from a siliceous ankerite rock rather poor in lime. Under the influence of shearing stress the silica and ankerite would react to form the amphibole.

$$(MgFe)\ CO_3 + SiO_2 \longrightarrow (MgFe)\ SiO_3 + CO_2$$

With a change of metamorphism to dynamothermal this amphibole with the addition of alumina would be replaced by garnet. Silica present represents that left over from the original reaction.

Thus this very interesting rock which consists of a pyropealmandine garnet, cummingtonite and quartz, may be the result of the metamorphism of an igneous rock, or that of a sediment.

## VI.—GEOLOGICAL HISTORY OF THE AREA.

Descriptions have been given of a series of metamorphosed sediments and basic igneous rocks which have been intruded by later granite gneisses, granite and basic intrusives.

The bulk of the metamorphosed sediments consisted originally of interbedded sandstones and mudstones laid down in an early Pre-Cambrian sea. Occasionally beds rich in iron carbonates were deposited. The frequent occurrence of lime bearing minerals in the quartzites indicates the presence of limy intercalations in the original sandstones. Sills and flows of basic igneous rocks of tholeiitic and ultra basic composition were associated with these sediments. The grading of quartzites into mica schists indicates that whereas the sedimentation conditions were constantly changing, these changes were gradational.

After the close of the early Pre-Cambrian sea the accumulated sediments and igneous rocks were deeply buried and folded. As a result of this folding the series was thrown into an anticlinal structure. Minor schistose structures were produced in the basic igneous rocks and the quartzites were granulated.

This orogenic period was closed by a long-continued intrusion of a granite magma. It is believed that all the acid igneous rocks and granite gneiss in the Area are a part of this intrusion, but that with declining stress the later intrusions developed correspondingly fewer structures. Most of the metamorphism of the Area (which is predominantly of a thermal nature) is a result of this invasion of magmatic material into the sedimentary series.

This granite magma, the earlier intrusions of which crystallised as porphyritic microcline granite, was first intruded under strong stresses with consequent granulation of the phenocrysts and production of an augen structure. Before consolidation was completed a non-porphyritic microcline granite was emplaced farther to the north. In the short interval between the two intrusions there was a decline in the tectonic forces. The intrusive granite picked up fragments of older basic igneous rocks with the production of hybrid rock types. These basic rocks were already solidified before the acid residuum was emplaced, and were possibly evolved in the same magma reservoir as the granite magma by some process of contrasted differentiation, or more likely belong to the sills and flows of basic igneous rocks associated with the meta-sedimentary series. The main Darling Range granite bathylith, together with its end stage products (aplites, pegmatites, quartz veins and felspar porphyries) followed farther to the west and south-west. Being intruded at a time when earth movements had practically ceased, cataclastic and flow structures are entirely absent.

The final phase of igneous activity is represented by the basic dykes, which intrude the granite and metamorphics along tension joints parallel to the direction of principal stress. It is suggested that the basic dykes originated from a magma reservoir which was very close to the present land surface in the western part of the Area. In certain places increased stress towards the end of crystallisation has resulted in the volatiles and gases playing an important part in late stage magmatic processes leading to the development of amphibole-porphyroblastic texture.

Later tectonic movements are represented by the production of a brecciated shear zone. Its age is unknown, but it was later than the basic intrusives and prior to the formation of the duricrust.

The area was then subjected to long continued erosion, and there is no evidence of any deposition of sedimentary series since Pre-Cambrian times.

Woolnough (1918, p. 385) considers that the superficial capping of ubiquitous laterite or duricrust belongs to a recent period when a great part of Western Australia had been reduced to a peneplain. Uplift of the peneplain followed and since that time the area has been dissected by streams as outlined in the physiographic section of this paper.

## VII.—ACKNOWLEDGMENTS.

The work was made possible through a grant to Professor E. de C. Clarke from the Council for Scientific and Industrial Research for research into the Pre-Cambrian of the western part of the West Australian shield. Our thanks are due to the officers of the Lands and Survey Department and the W.A. Government Railways who readily made available valuable data necessary for the compilation of the map. To Professor E. de C. Clarke, Dr. R. T. Prider and Dr. Dorothy Carroll we wish to express our indebtedness for many helpful suggestions and discussions during the preparation of this paper. For assistance in the revision of this text our thanks are again due to Professor E. de C. Clarke, Dr. R. T. Prider and Mr. H. G. Higgins. In the preparation of the figures we are very grateful to Mr. H. J. Smith for his excellent photography.

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